

Appendix F

Example of budgetary estimation of capital and operating cost of membrane reclamation system

Mark Wilf *

Wastewater reclamation system: 40,000 m³/day (10.6 mgd) product water capacity.

Membrane process: immersed (vacuum driven) membrane filtration followed by RO and advanced oxidation process (AOP).

TABLE F.1
Composition of the secondary effluent

pH	7.8	Temperature	16–26 C
Ca	113.1 ppm	Mg	29.1 ppm
Na	240.0 ppm	HCO ₃	194.0 ppm
Cl	212.0 ppm	NH ₄	35.5 ppm
NO ₃	2.0 ppm	SO ₄	459.0 ppm
SiO ₂	18.3 ppm	PO ₄	2.7 ppm

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TABLE F.2

Sizing of membrane units

MF unit net filtrate capacity	47,000 m ³ /day (12.4 mgd)
Recovery rate	90%
Raw water flow	2,175 m ³ /hr (9,580 gpm)
Instantaneous capacity factor	1.25
Instantaneous filtrate capacity	1.25 × 47,000 = 58,750 m ³ /day (15.5 mgd)
Instantaneous permeate flux rate	42 l/m ² /hr (25 gfd)
Membrane area per module	50 m ² (540 ft ²)
Number of membrane modules required	58,750 × 1,000 / (24 × 42 × 50) = 1,166
Number of trains	5 + 1
Number of modules per train	235
Total number of modules in the system	1,410
Installed membrane filtration capacity	1,410 × 50 × 42 × 24 / 1000 = 71,064 m ³ /day (18.8 mgd)
RO unit permeate capacity	40,000 m ³ /day (10.6 mgd)
Recovery rate	85%
Average permeate flux rate	18.7 l/m ² /hr (11 gfd)
Membrane area per element	40 m ² (430 ft ²)
Recovery rate	85%
Number of RO membrane trains:	4
Permeate capacity per train	10,000 m ³ /day (2.64 MGD)
Number of elements per train	10000m ³ /day × 1000l/m ³ / (18.7l/m ² /hr × 40m ² × 24 hr) = 557 elements
Number of pressure vessels (7 elements/vessel)	557/7 = 80 pressure vessels
Pressure vessel array, 2 stages, recovery rate 85%	54:26 = 80 PV (560 elements)

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TABLE F.3
Summary of process sequence during operation of membrane filtration unit

Process step	Objective	Duration	Frequency
Permeation	Permeate production	15–60 min	Continuous
Backwash & tank deconcentration	Foulants removals	15–60 sec	Every 15–60 min
Chemicals enhanced backwash (CEB)	Foulants removal	1–15 min	Twice a day— once per week
Cleaning in place	Foulants removal	2–5 hr	Every 1–6 months
Integrity test	Verification of membrane integrity	20 min	Every 1–7 days

TABLE F.4
Summary of energy usage distribution in membrane filtration unit

Power component	Efficiency Motor (Pump)	Pressure, bar (psi)	Flow, m ³ /hr (gpm)	Active, %	Power, kW
Feed pump	0.95 (0.80)	1.0 (14.5)	2,275 (10,010)	93.0	80.3
Filtrate pump	0.95 (0.80)	0.8 (11.6)	2,175 (9,580)	93.0	61.6
BW pump	0.95 (0.80)	1.4 (20.3)	1,000 (4,400)	16.6	8.5
Cleaning pumps	0.95 (0.80)	1.7 (24.7)	180 (800)	6.1	0.7
Cleaning tank heater				8.0	4.0
Blower				2.8	2.5
Valve actuators				3.3	0.4
Instr. & PLC				100.0	12.0
Total					170.0

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TABLE F.5
Summary of chemical consumption for permeability restoration in membrane filtration unit (*)

Cleaning step	Chemical	Dosage, ppm	Kg/day (**) (lb/day)	\$/t (**)	\$/day
CEB1	NaOCl	10	4.6 (10.1)	750	3.4
CEB2	HCl	365	252 (447)	300	75.6
CIP1	NaOH	2000	285 (555)	500	142.2
CIP2	NaOCl	10	0.4 (0.9)	750	0.3
CIP3	Citric	20000	12.4 (27.3)	2200	27.2
CIP4	Detergent	500	3.6 (7.9)	2000	7.2
Total			255.9		

* Calculation of chemical usage is based on the chemicals dosage rate, frequency and duration of chemical enhanced backwash (CEB) and volume of the cleaning tank, similarly to calculations for the chemical usage in the RO unit, included in the Example 16.2.

** As 100% concentration

TABLE F.6
Components of water cost in MF unit. Filtrate capacity 47,000 m³/day (12.4 mgd)

Cost component	\$/day	\$/m ³	\$/kgallon
<i>Capital cost</i>			
Direct equipment capital cost @6%, 20 years (8.72% depreciation)	1,208	0.027	0.102
Site and Indirect capital cost (150%)	1,812	0.041	0.155
<i>Operating and maintenance</i>			
Power@ \$0.10/kWhr	408	0.009	0.035
Chemicals	255.9	0.006	0.022
Operation and maintenance	438 (personnel of 4 @ 40,000/y)	0.010	0.038
Membrane replacement	550(7 years membrane life)	0.012	0.045
Total	3,357	0.105	0.397

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TABLE F.7
Summary of energy usage distribution in reverse osmosis unit

Power component	Efficiency motor (pump)	Pressure, bar (psi)	Flow, m ³ /hr (gpm)	Active %	Power kW
Feed pump	0.95 (0.80)	15.0 (145)	1,958 (8,621)	95.0	998.0
Product water pump	0.95 (0.80)	5 (72.5)	1,667 (7,430)	95.0	289.0
Auxiliary equipment including cleaning system					10.0
Instr. & PLC				100.0	12.0
Total					1,311.0

TABLE F.8
Summary of chemical consumption for permeability restoration in reverse osmosis unit*

Location/ operation	Chemical	Dosage, ppm (frequency)	Kg/day (**) (lb/day)	\$/t (**)	\$/day
Dosing to feed	NaOCl	10 (continuously)	470 (1,035)	1,000	470
Dosing to feed	Scale inhibitor	2 (continuously)	94 (207)	2,500	235
Dosing to feed	H2SO4	30 (continuously)	1,410 (3,105)	150	211
Low pH cleaning	Citric acid	1% (every 3 month)	60 (132)	1,500	90
High pH cleaning	NaOH	0.2% (every 3 month)	12 (27)	700	8
Total					1,114

* Calculation of chemical usage is based on the chemicals dosage rate, frequency and duration of chemical enhanced backwash (CEB) and volume of the cleaning tank, similarly to calculations for the chemical usage in the RO unit, included in the Example 16.2.

** As 100% concentration

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TABLE F.9
Components of water cost in RO unit. Permeate capacity 40,000 m³/day (10.6 mgd)

Cost component	\$/day	\$/m ³	\$/kgallon
<i>Capital cost</i>			
Direct equipment capital cost @6%, 20 years (8.72% depreciation)	2,655	0.066	0.250
Site and indirect capital cost (150%)	3,982	0.099	0.375
<i>Operating and maintenance</i>			
Power@ \$0.10/kWhr	3,146	0.079	0.223
Chemicals	1,114	0.028	0.106
Operation and maintenance	438 (personnel of 4 @ 40,000/y)	0.010	0.038
Membrane replacement	570 (7 years membrane life)	0.014	0.052
Total	11,905	0.30	1.13

TABLE F.10
Configuration of AOP system, 40,000 m³/day (10.6 mgd) flow

Number of UV reactors	3 (2+1)
Flow per reactor	20,000 m ³ /day
Power requirement per reactor	80 kW
Hydrogen peroxide dosing	6 ppm
Chlorine quenching dosing	12 ppm

TABLE F.11
Cost components of AOP. 40,000 m³/day (10.6 mgd) flow

Cost component	\$/day	\$/m ³	\$/kgallon
<i>Capital cost</i>			
Equipment capital cost @6%, 20 years (8.72% depreciation)	162	0.004	0.015
<i>Operating and maintenance</i>			
Power@ \$0.10/kWhr	384	0.010	0.040
Hydrogen peroxide	360	0.009	0.034
Hypochlorite	1,920	0.048	0.182
Total	2,826	0.071	0.271